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PROFILE MEASURING DEVICE-002 (PMD-002) Final  
Test Report (Thiokol Corp.) 45 p

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# Qualification for the Profile Measuring Device-002 (PMD-002) Final Test Report

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Qualification for the Profile  
Measuring Device -002 (PMD-002)  
Final Test Report

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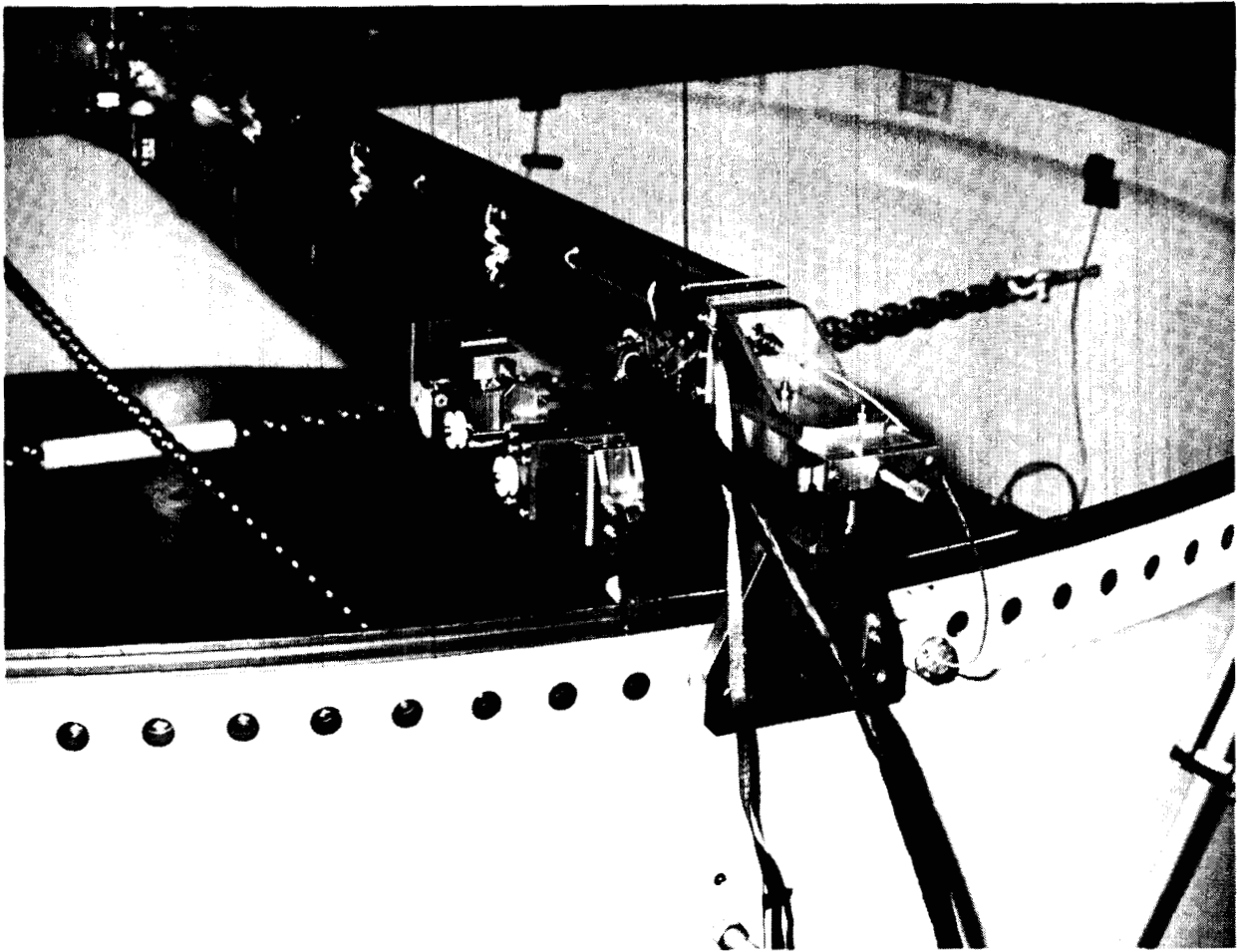
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The redesigned solid rocket motor (RSRM) Profile Measuring Device (PMD) is an electro-mechanical device used for measuring and recording the profile and diameter of RSRM field joint cases on both the tang and clevis ends. The system consists of a cross beam assembly that mounts to the RSRM case using existing assembly pin holes.

The cross beam assembly supports a radius measuring arm that contains a digital electronic gage, a resolver (for angular measurement), a gear train drive assembly (for rotating the arm), and an adjustable counterweight. The cross beam assembly is composed of four similar legs that interface at the center for ease of operation and mobility.

During measurement operations, the digital linear gage measures the relative distance on the RSRM joint to a point at the approximate center of the case. This point is also the center of rotation of the resolver/shaft and radius arm assembly. The radius arm assembly and resolver are driven radially by a servomotor gear train assembly, while radial deviations and angular positions are being stored. An offset circle (based on the true diameter of the RSRM case) is plotted. The data obtained previously is then processed to attain a fit to a true offset circle.

## ABSTRACT

The revised Profile Measuring Device Serial No. 003 (PMD-003) was certified for use on RSRM case field joints on 3 Dec 1988 at Thiokol Corporation. An additional Profile Measuring Device Serial No. 002 (PMD-002), of identical design, was certification tested for use on RSRM case field joint on 6 Oct 1989 at Thiokol, Buildings H-5 and H-7 in Clearfield, Utah in accordance with CTP-0162. The repeatability test was performed on one set of field joint hardware (one tang, capture feature cylinder, and one clevis, lightweight cylinder). The mating test was performed on one tang ring simulator and three clevis filament wound case adapter rings.

All data is believed to be accurately acquired without compromise. It has provided the necessary data needed to develop a statistical model for the components of variance and measurement bias of the interference fit prediction of PMD-002.

It is recommended that PMD-002 be qualified to measure RSRM hardware field joint dimensions under temperature controlled conditions ( $\pm 1^\circ\text{F}$  ambient) for interference fit prediction as a backup tool for PMD-003.

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## INTRODUCTION

The PMD is used to measure the radii of certain locations of the RSRM field joint flight hardware. These measurements are used to predict case mating conditions to establish acceptance criteria.

The testing was performed on PMD-002 to identify tool bias and uncertainty of when predicting interference fit.

No measurement standard exists to determine the absolute accuracy of PMD-002, therefore it is only used for relative measurements such as interference fit. PMD-002 was qualified to predict interference fit by subtracting the measurements of two tang and clevis joint readings and comparing the prediction to feeler gage measurements of the mated pair. O-rings were not used on the mated joints.

The repeatability test was conducted in the temperature controlled room ( $\pm 1^\circ\text{F}$ ) at building H-5 and the mating test was conducted in the Hydrotest Pit at Building H-7 in Clearfield, UT.

This test was not an attempt to certify PMD as an absolute measuring device traceable to the National Institute of Standards Technology.

### 1.1 TEST ITEM DESCRIPTION

The repeatability test was performed on one tang, capture feature (CF) cylinder, and one clevis, lightweight (LW) cylinder:

Tang, CF Cylinder, P/N 1U52982-03, SN 0000027

Clevis, LW Cylinder, P/N 1U50717-05, SN 0000007

The mating test was performed on one tang ring simulator and three clevis filament wound case (FWC) adapter rings:

Tang Simulator Ring, P/N 7U52974-01

Clevis FWC Adapter Ring, P/N 180025-003 VPT 0046

Clevis FWC Adapter Ring, P/N 180024-006 VPT 0038

Clevis FWC Adapter Ring, P/N 180024-006 VPT 0042

The three mating configurations were accomplished by changing the clevis ring between mating tests. The rings were measured prior to the qualification test with the qualified PMD-003, and the tang ring simulator was modified to produce a sufficient interference gap when mated with the clevis ring of the smallest diameter.

During the mating test, only three pins were applied to the joints and O-rings were not used in the mated joints. The following items were used to perform the comparison measurements:

Feeler Gage

Profile Measuring Device 97M50225

Radius Arm Calibration Assembly 97M50420

## 1.2 TEST SET-UP

### 1.2.1 Case Cylinders and Rings

The cases and rings were set in the temperature controlled room of H-5 and placed on four equally spaced aluminum blocks which had been previously leveled.

### 1.2.2 PMD-002 Calibration Fixture

The PMD-002 calibration fixture was installed and leveled in the temperature controlled room of H-5.

### 1.2.3 Sensors

During calibration, barometric pressure, humidity, and temperature were monitored by an H/P air sensor, model number 10751A, of PMD-003. The velocity of light compensation factor was entered into the laser fixture of PMD-002. During measurement, only temperature stability was of interest. The temperature stability was monitored using the internal thermocouple of the PMD arm.

### 1.2.4 Mating Test

The rings were mated with tang up and clevis down at Building H-7. O-rings were not used during any portion of the mating test. There were no complications while mating the rings since all three mating configurations had an interference gap.

## 1.3 TEST ENVIRONMENT

The cylinders and rings were measured with PMD-002 in the temperature controlled environment of H-5. The temperature was controlled to  $\pm 1^\circ\text{F}$ . The rings were measured and the interference gap measured in the Hydrotest Pit of H-7. The environment for feeler gages is not critical.

2

TEST OBJECTIVES

The objective of this test was to qualify PMD-002 as an accurate measuring device for determining interference fit.

3

SUMMARY/CONCLUSIONS/RECOMMENDATIONS

3.1 SUMMARY

The repeatability test was performed on one set of field joint hardware (one tang, CF cylinder, and one clevis, LW cylinder). The mating test was performed on one tang ring simulator and three clevis FWC adapter rings.

All data is believed to be accurately acquired without compromise. It has provided the necessary data needed to develop a statistical model for the components of variance and measurement bias of the interference fit prediction of PMD-002.

3.2 CONCLUSIONS

The following is a one-on-one correlation of development objectives with test results. Detailed results can be found in the referenced sections.

| <u>Objective</u>  | <u>Results</u>   |
|---|--|
| Qualify PMD-002 as an accurate measuring device for determining interference fit. | Qualified--PMD-002 is qualified to measure RSRM cases in an environment controlled to $\pm 1^{\circ}\text{F}$ with the case and PMD-002 stabilized at a fixed ambient temperature. |

3.3 RECOMMENDATIONS

3.3.1 Tang Ring Simulator and Clevis FWC Adaptive Ring Test

A test should be performed on the tang ring simulator and the three clevis FWC adapter rings to correlate the data between PMD-002 and PMD-003. This would allow an acceptance criteria for interference fit of field joints based on PMD data even if the mated pair were not measured with the same PMD.

### 3.3.2 Tang and Clevis Ring Test

A test should be performed to test the tang ring and one of the clevis rings to be used as relative measurement standards for PMD-002 and PMD-003. This would provide another means to monitor tool drift during normal use and maintain measurement integrity after tool repair.

### 3.3.3 Lifting Brackets

Lifting brackets should be designed and installed on the PMD for easier and safer handling.

## 4

### APPLICABLE DOCUMENTS

The latest revisions of the following documents, unless otherwise specified, are applicable to this report.

|               |  |
|---------------|--|
| CTP-0162      | Qualification Test Plan for the Profile Measuring Device-002 (PMD-002) |
| 97M50225      | Profile Measuring Device   |
| 97M50420      | Radius Arm Calibration Assembly  |
| MIL-STD-45662 | Calibration System Requirements  |

## 5

### INSTRUMENTATION

Temperature of both the PMD and the tang/clevis joint were recorded by PMD-002 using the integrated circuit temperature sensors. Calibration of the PMD system was performed in accordance with 97M50420.

All instrumentation and/or systems calibration requirements were in conformance with MIL-STD-45662. All instruments were mechanically and electrically zeroed before and after testing and when required by the operating limits of the test.

## 6

### PHOTOGRAPHIC COVERAGE

Photographic coverage was not required for this test.

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## RESULTS/DISCUSSION

### 7.1 INTRODUCTION

PMD-002 was qualified in the event that PMD-003 was not operational. The test procedure was as follows:

#### 7.1.1 Clevis and Tang Joint Repeatability Measurements

The two cylinders were soaked at a specific temperature between 66° through 72°F. Calibration and measurement procedures began upon temperature stabilization, and the temperature was held to  $\pm 1^\circ\text{F}$ . Both the tang and clevis joints were measured using the Interference Fit Tips 9 and 11 of PMD-002 to indicate PMD-002 measurement uncertainty in the following manner:

- 1) Tips 9 and 11 of PMD-002 were calibrated
- 2) PMD-002 was installed on the clevis joint
- 3) PMD-002 measurements (2 passes) were taken using Tip 9
- 4) PMD-002 was installed on the tang joint
- 5) PMD-002 measurements (2 passes) were taken using Tip 11
- 6) Steps 2 through 5 were performed an additional two times
- 7) Tips 9 and 11 of PMD-002 were calibrated
- 8) Steps 2 through 7 were performed an additional four times

#### 7.1.2 Mating Test

The rings were first measured with PMD-002 to assess the tools' predicted interference gap of the mated rings. The measurements were taken in the following manner:

- 1) Tips 9 and 11 of PMD-002 were calibrated
- 2) PMD-002 was installed on the tang ring simulator
- 3) PMD-002 measurements (2 passes) were taken using Tip 11
- 4) PMD-002 was installed on the first clevis FWC adapter ring
- 5) PMD-002 measurements (2 passes) were taken using Tip 9
- 6) PMD-002 was installed on the second clevis FWC adapter ring
- 7) PMD-002 measurements (2 passes) were taken using Tip 9
- 8) PMD-002 was installed on the third clevis FWC adapter ring
- 9) PMD-002 measurements (2 passes) were taken using Tip 9
- 10) Tips 9 and 11 of PMD-002 were calibrated
- 11) Steps 2 through 10 were performed an additional two times

The rings were moved to the north Hydrotest Pit at H-7 and were mated. The interference gap was measured at every degree location under these conditions to derive comparison data. The feeler gages used were in increments of 1.0 mil, so 0.5 mil was added to each location to maintain an accurate average value for feeler gage prediction of the interference gap.

## 7.2 OBJECTIVES

The objective of this test was to qualify PMD-002 as an accurate measuring device for determining interference fit.

## 7.3 RESULTS AND DISCUSSION

Appendix E contains the  $3\text{-}\sigma$  uncertainty for PMD radial measurements for the measured locations. The uncertainty for production mode measurements of Tips 11 and 9 are 1.12 mil and 1.11 mil, respectively.

The measurement bias for each tip is not possible to determine because of the lack of an absolute standard, but a bias can be estimated for the difference between two tips. A detailed look at the results for the bias was done for the capture feature interference.

PMD-002 estimated the capture feature interference (Tips 11 through 9) of the three matings to be -1.425, -2.155, and -2.075 mil (a negative sign denotes an interference gap). The rings were mated and the clearance of each mating was measured with feeler gages. The average clearance of each mate was -1.15, -1.93, and -1.92 mil. The bias of PMD-002 is estimated to be 2.18 mil (PMD-002 underpredicts interference fit).

The  $3\text{-}\sigma$  uncertainty of the estimation of the capture feature interference is  $\pm 1.6985$  mil. Since the bias is approximately 2.2 mil and the uncertainty of the estimation of the bias is approximately  $\pm 1.7$  mil, a criterion requiring at least line-on-line interference with a confidence level of  $3\text{-}\sigma$  would require raw PMD-002 data to estimate a radial interference gap of no larger than 0.5 mil. This analysis assumes data is collected in a thermally controlled environment ( $\pm 1^\circ\text{F}$ ).

PMD-002 is qualified to be used to measure RSRM cases in an environment controlled to  $\pm 1^\circ\text{F}$  with the case and PMD-002 stabilized at a fixed ambient temperature.

The engineering specification for acceptance criteria for RSRM case field joint interference should apply to PMD-002 raw data derived under the above conditions and should take into account the bias and uncertainty developed in CTP-0162.

Data acquired from PMD-002 in an uncontrolled environment is unqualified under the constraints of this test. Requalification would be required for any design changes that are believed to influence measurement integrity.

PMD-002 is qualified for use in determining the relative measurements of interference fit and should not be used to determine absolute dimensional values. In the event that the calibration method of PMD-002 acquires traceability to the National Institute of Standards Technology, this position should be reconsidered.

The calibration system is the major contributor to overall measurement uncertainty. Although there is an accuracy check for the PMD-002 system, only certain components of PMD-002 can be calibrated. This may allow the tool's accuracy to drift without timely recognition by the operator.

The setup and handling methods now being used could cause damage to the PMD tool during the mount and dismount process with the cases.

Appendix A

PMD-002 Repeatability Test Data

Tang Joint, P/N 1U52982-03 S/N 0000027

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Appendix A  
PMD-002 Repeatability Test Data

Tang Joint, P/N 1U52982-03 S/N 0000027

Calibration #1

|        | Calibration Number | PMD Temp. |
|--------|--------------------|-----------|
| Tip 11 | 70.8720            | 69.2      |

The new calibration number was used in the PMD-002 software.

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 1st Meas. | 143.7632  | 69.2      | 69.5        |
| 2nd Meas. | 143.7633  | 69.2      | 69.5        |

PMD-002 was removed and replaced.

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 3rd Meas. | 143.7633  | 69.8      | 70.0        |
| 4th Meas. | 143.7635  | 69.9      | 70.1        |

PMD-002 was removed and replaced.

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 5th Meas. | 143.7635  | 70.3      | 70.6        |
| 6th Meas. | 143.7637  | 70.3      | 70.5        |

PMD-002 was removed and calibrated.

Calibration #2

|        | Calibration Number | PMD Temp. |
|--------|--------------------|-----------|
| Tip 11 | 70.8720            | 70.0      |

The new calibration number was used in the PMD-002 software.

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 7th Meas. | 143.7634  | 69.7      | 70.1        |
| 8th Meas. | 143.7634  | 69.7      | 70.1        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 9th Meas.  | 143.7636  | 70.3      | 70.4        |
| 10th Meas. | 143.7636  | 70.2      | 70.4        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 11th Meas. | 143.7639  | 70.3      | 70.4        |
| 12th Meas. | 143.7639  | 70.3      | 70.4        |

PMD-002 was removed and calibrated.

### Calibration #3

|        | Calibration Number | PMD Temp. |
|--------|--------------------|-----------|
| Tip 11 | 70.8714            | 70.0      |

The new calibration number was used in the PMD-002 software.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 13th Meas. | 143.7633  | 70.6      | 70.8        |
| 14th Meas. | 143.7633  | 70.5      | 70.8        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 15th Meas. | 143.7628  | 70.7      | 70.5        |
| 16th Meas. | 143.7627  | 70.7      | 70.5        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 17th Meas. | 143.7629  | 70.5      | 70.4        |
| 18th Meas. | 143.7630  | 70.5      | 70.5        |

PMD-002 was removed and calibrated.

#### Calibration #4

|        | Calibration Number | PMD Temp. |
|--------|--------------------|-----------|
| Tip 11 | 70.8713            | 70.3      |

The new calibration number was used in the PMD-002 software.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 19th Meas. | 143.7624  | 70.4      | 70.4        |
| 20th Meas. | 143.7624  | 70.4      | 70.4        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 21st Meas. | 143.7618  | 70.4      | 70.4        |
| 22nd Meas. | 143.7618  | 70.4      | 70.4        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 23rd Meas. | 143.7617  | 70.4      | 70.4        |
| 24th Meas. | 143.7617  | 70.4      | 70.5        |

PMD-002 was removed and calibrated.

#### Calibration #5

|        | Calibration Number | PMD Temp. |
|--------|--------------------|-----------|
| Tip 11 | 70.8714            | 69.8      |

The new calibration number was used in the PMD-002 software.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 25th Meas. | 143.7623  | 70.1      | 70.4        |
| 26th Meas. | 143.7623  | 70.1      | 70.4        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 27th Meas. | 143.7621  | 70.3      | 70.5        |
| 28th Meas. | 143.7622  | 70.3      | 70.6        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 29th Meas. | 143.7624  | 70.6      | 70.9        |
| 30th Meas. | 143.7624  | 70.6      | 70.8        |

PMD-002 was removed and calibrated.

#### Calibration #6

|        | Calibration Number | PMD Temp. |
|--------|--------------------|-----------|
| Tip 11 | 70.8705            | 70.8      |

Appendix B  
PMD-002 Repeatability Test Data

Clevis Joint, P/N 1U50717-05 S/N 0000007

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Appendix B  
PMD-002 Repeatability Test Data

Clevis Joint, P/N 1U50717-05 S/N 0000007

Calibration #1

|       | Calibration Number | PMD Temp. |
|-------|--------------------|-----------|
| Tip 9 | 71.1998            | 69.0      |

The new calibration number was used in the PMD-002 software.

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 1st Meas. | 143.7586  | 69.5      | 69.7        |
| 2nd Meas. | 143.7586  | 69.5      | 69.6        |

PMD-002 was removed and replaced.

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 3rd Meas. | 143.7597  | 70.1      | 70.3        |
| 4th Meas. | 143.7598  | 70.1      | 70.3        |

PMD-002 was removed and replaced.

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 5th Meas. | 143.7591  | 70.4      | 70.7        |
| 6th Meas. | 143.7592  | 70.4      | 70.6        |

PMD-002 was removed and calibrated.

Calibration #2

|       | Calibration Number | PMD Temp. |
|-------|--------------------|-----------|
| Tip 9 | 71.1988            | 70.5      |

The new calibration number was used in the PMD-002 software.

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 7th Meas. | 143.7573  | 70.2      | 70.5        |
| 8th Meas. | 143.7573  | 70.1      | 70.5        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 9th Meas.  | 143.7583  | 70.4      | 70.5        |
| 10th Meas. | 143.7583  | 70.5      | 70.5        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 11th Meas. | 143.7579  | 70.6      | 70.6        |
| 12th Meas. | 143.75809 | 70.6      | 70.6        |

PMD-002 was removed and calibrated.

### Calibration #3

|       | Calibration Number | PMD Temp. |
|-------|--------------------|-----------|
| Tip 9 | 71.1985            | 69.9      |

The new calibration number was used in the PMD-002 software.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 13th Meas. | 143.7574  | 70.9      | 71.1        |
| 14th Meas. | 143.7580  | 71.3      | 71.4        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 15th Meas. | 143.7572  | 70.9      | 70.7        |
| 16th Meas. | 143.7571  | 70.7      | 70.6        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 17th Meas. | 143.7573  | 70.6      | 70.5        |
| 18th Meas. | 143.7574  | 70.7      | 70.6        |

PMD-002 was removed and calibrated.

#### Calibration #4

|       | Calibration Number | PMD Temp. |
|-------|--------------------|-----------|
| Tip 9 | 71.1992            | 70.3      |

The new calibration number was used in the PMD-002 software.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 19th Meas. | 143.7582  | 70.4      | 70.4        |
| 20th Meas. | 143.7582  | 70.5      | 70.4        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 21st Meas. | 143.7586  | 70.5      | 70.5        |
| 22nd Meas. | 143.7586  | 70.4      | 70.4        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 23rd Meas. | 143.7582  | 70.5      | 70.6        |
| 24th Meas. | 143.7582  | 70.6      | 70.6        |

PMD-002 was removed and calibrated.

#### Calibration #5

|       | Calibration Number | PMD Temp. |
|-------|--------------------|-----------|
| Tip 9 | 71.1989            | 69.75     |

The new calibration number was used in the PMD-002 software.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 25th Meas. | 143.7580  | 70.2      | 70.4        |
| 26th Meas. | 143.7580  | 70.3      | 70.5        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 27th Meas. | 143.7578  | 70.6      | 70.7        |
| 28th Meas. | 143.7578  | 70.6      | 70.7        |

PMD-002 was removed and replaced.

|            | Ave. Dia. | PMD Temp. | Joint Temp. |
|------------|-----------|-----------|-------------|
| 29th Meas. | 143.7586  | 70.8      | 70.8        |
| 30th Meas. | 143.7586  | 70.8      | 70.9        |

PMD-002 was removed and calibrated.

#### Calibration #6

|       | Calibration Number | PMD Temp. |
|-------|--------------------|-----------|
| Tip 9 | 71.1982            | 70.9      |

Appendix C  
PMD-002 Mating Test Data

Measurement Data for Tang and Clevis Rings

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Appendix C  
PMD-002 Mating Test Data

Measurement Data for Tang and Clevis Rings

Calibration #1

|        | Calibration Number | PMD Temp. |
|--------|--------------------|-----------|
| Tip 9  | 71.1986            | 70.0      |
| Tip 11 | 70.8716            | 70.1      |

The new calibration numbers were entered into the PMD-002 software.

Tang Ring Simulator Measurements

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 1st Meas. | 143.6912  | 70.1      | 69.9        |
| 2nd Meas. | 143.6911  | 70.1      | 69.9        |

Clevis FWC Adapter Ring Measurement, P/N 180025-003, VPT 0046

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 1st Meas. | 143.7235  | 70.3      | 70.6        |
| 2nd Meas. | 143.7235  | 70.3      | 70.6        |

Clevis FWC Adapter Ring Measurement, P/N 180024-006, VPT 0038

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 1st Meas. | 143.7377  | 70.1      | 70.5        |
| 2nd Meas. | 143.7377  | 70.1      | 70.5        |

Clevis FWC Adapter Ring Measurement, P/N 180024-006, VPT  
0042

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 1st Meas. | 143.7364  | 70.2      | 70.2        |
| 2nd Meas. | 143.7364  | 70.1      | 70.2        |

Calibration #2

|        | Calibration Number | PMD Temp. |
|--------|--------------------|-----------|
| Tip 9  | 71.1983            | 70.5      |
| Tip 11 | 70.8711            | 70.5      |

The new calibration numbers were entered into the PMD-002 software.

Tang Ring Simulator Measurements

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 3rd Meas. | 143.6954  | 70.3      | 70.2        |
| 4th Meas. | 143.6954  | 70.3      | 70.2        |

Clevis FWC Adapter Ring Measurement, P/N 180025-003, VPT  
0046

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 3rd Meas. | 143.7231  | 70.5      | 70.5        |
| 4th Meas. | 143.7231  | 70.6      | 70.6        |

Clevis FWC Adapter Ring Measurement, P/N 180024-006, VPT  
0038

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 3rd Meas. | 143.7380  | 70.3      | 70.1        |
| 4th Meas. | 143.7381  | 70.4      | 70.2        |

Clevis FWC Adapter Ring Measurement, P/N 180024-006, VPT  
0042

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 3rd Meas. | 143.7355  | 70.3      | 70.2        |
| 4th Meas. | 143.7355  | 70.3      | 70.2        |

Calibration #3

|        | Calibration Number | PMD Temp. |
|--------|--------------------|-----------|
| Tip 9  | 71.1983            | 70.4      |
| Tip 11 | 70.8718            | 70.5      |

The new calibration numbers were entered into the PMD-002 software.

Tang Ring Simulator Measurements

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 5th Meas. | 143.6964  | 70.4      | 70.1        |
| 6th Meas. | 143.6964  | 70.4      | 70.1        |

Clevis FWC Adapter Ring Measurement, P/N 180025-003, VPT  
0046

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 5th Meas. | 143.7228  | 70.4      | 70.5        |
| 6th Meas. | 143.7227  | 70.4      | 70.4        |

Clevis FWC Adapter Ring Measurement, P/N 180024-006, VPT  
0038

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 5th Meas. | 143.7376  | 70.3      | 70.4        |
| 6th Meas. | 143.7376  | 70.3      | 70.4        |

Clevis FWC Adapter Ring Measurement, P/N 180024-006, VPT  
0042

|           | Ave. Dia. | PMD Temp. | Joint Temp. |
|-----------|-----------|-----------|-------------|
| 5th Meas. | 143.7364  | 70.3      | 70.2        |
| 6th Meas. | 143.7365  | 70.3      | 70.2        |

Ending Calibration

|        | Calibration Number | PMD Temp. |
|--------|--------------------|-----------|
| Tip 9  | 71.1983            | 70.5      |
| Tip 11 | 70.8711            | 70.5      |

Appendix D  
PMD-002 Mating Test Data

Tang Ring Mated With Clevis Rings

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## Appendix D

### PMD-002 Mating Test Data

#### Tang Ring Mated With Clevis Rings

Tang Ring Simulator Mated to the Clevis FWC Adapter Ring, 180025-003, VPT 0046.

The interference gap was measured using feeler gages at every degree location.

|     |       |     |       |     |       |     |       |
|-----|-------|-----|-------|-----|-------|-----|-------|
| 1.  | 0.015 | 2.  | 0.015 | 3.  | 0.014 | 4.  | 0.013 |
| 5.  | 0.014 | 6.  | 0.014 | 7.  | 0.014 | 8.  | 0.013 |
| 9.  | 0.013 | 10. | 0.013 | 11. | 0.012 | 12. | 0.012 |
| 13. | 0.012 | 14. | 0.012 | 15. | 0.011 | 16. | 0.011 |
| 17. | 0.010 | 18. | 0.010 | 19. | 0.010 | 20. | 0.010 |
| 21. | 0.010 | 22. | 0.009 | 23. | 0.009 | 24. | 0.009 |
| 25. | 0.009 | 26. | 0.009 | 27. | 0.010 | 28. | 0.010 |
| 29. | 0.010 | 30. | 0.010 | 31. | 0.011 | 32. | 0.011 |
| 33. | 0.011 | 34. | 0.011 | 35. | 0.011 | 36. | 0.011 |
| 37. | 0.011 | 38. | 0.012 | 39. | 0.012 | 40. | 0.012 |
| 41. | 0.012 | 42. | 0.012 | 43. | 0.012 | 44. | 0.011 |
| 45. | 0.010 | 46. | 0.010 | 47. | 0.009 | 48. | 0.009 |
| 49. | 0.008 | 50. | 0.008 | 51. | 0.009 | 52. | 0.009 |
| 53. | 0.008 | 54. | 0.008 | 55. | 0.008 | 56. | 0.008 |
| 57. | 0.008 | 58. | 0.007 | 59. | 0.007 | 60. | 0.007 |
| 61. | 0.007 | 62. | 0.006 | 63. | 0.006 | 64. | 0.006 |
| 65. | 0.005 | 66. | 0.005 | 67. | 0.005 | 68. | 0.005 |
| 69. | 0.004 | 70. | 0.004 | 71. | 0.004 | 72. | 0.004 |
| 73. | 0.004 | 74. | 0.004 | 75. | 0.004 | 76. | 0.004 |

|            |            |            |            |
|------------|------------|------------|------------|
| 77. 0.004  | 78. 0.004  | 79. 0.004  | 80. 0.004  |
| 81. 0.004  | 82. 0.004  | 83. 0.004  | 84. 0.004  |
| 85. 0.004  | 86. 0.004  | 87. 0.004  | 88. 0.004  |
| 89. 0.004  | 90. 0.005  | 91. 0.005  | 92. 0.005  |
| 93. 0.005  | 94. 0.005  | 95. 0.005  | 96. 0.005  |
| 97. 0.005  | 98. 0.005  | 99. 0.005  | 100. 0.005 |
| 101. 0.005 | 102. 0.005 | 103. 0.006 | 104. 0.006 |
| 105. 0.006 | 106. 0.006 | 107. 0.006 | 108. 0.006 |
| 109. 0.006 | 110. 0.007 | 111. 0.007 | 112. 0.007 |
| 113. 0.007 | 114. 0.007 | 115. 0.007 | 116. 0.007 |
| 117. 0.007 | 118. 0.007 | 119. 0.007 | 120. 0.007 |
| 121. 0.007 | 122. 0.007 | 123. 0.007 | 124. 0.007 |
| 125. 0.007 | 126. 0.007 | 127. 0.007 | 128. 0.007 |
| 129. 0.007 | 130. 0.007 | 131. 0.007 | 132. 0.007 |
| 133. 0.007 | 134. 0.007 | 135. 0.007 | 136. 0.007 |
| 137. 0.007 | 138. 0.006 | 139. 0.006 | 140. 0.005 |
| 141. 0.005 | 142. 0.005 | 143. 0.004 | 144. 0.004 |
| 145. 0.004 | 146. 0.004 | 147. 0.004 | 148. 0.003 |
| 149. 0.003 | 150. 0.002 | 151. 0.002 | 152. 0.002 |
| 153. 0.002 | 154. 0.002 | 155. 0.002 | 156. NONE  |
| 157. NONE  | 158. NONE  | 159. NONE  | 160. NONE  |
| 161. NONE  | 162. NONE  | 163. NONE  | 164. NONE  |
| 165. NONE  | 166. NONE  | 167. 0.002 | 168. 0.003 |
| 169. 0.003 | 170. 0.003 | 171. 0.004 | 172. 0.004 |
| 173. 0.004 | 174. 0.004 | 175. 0.005 | 176. 0.005 |

|            |            |            |            |
|------------|------------|------------|------------|
| 177. 0.006 | 178. 0.006 | 179. 0.007 | 180. 0.007 |
| 181. 0.007 | 182. 0.007 | 183. 0.007 | 184. 0.007 |
| 185. 0.007 | 186. 0.008 | 187. 0.009 | 188. 0.009 |
| 189. 0.009 | 190. 0.010 | 191. 0.011 | 192. 0.011 |
| 193. 0.011 | 194. 0.012 | 195. 0.012 | 196. 0.012 |
| 197. 0.012 | 198. 0.012 | 199. 0.013 | 200. 0.013 |
| 201. 0.013 | 202. 0.014 | 203. 0.014 | 204. 0.014 |
| 205. 0.014 | 206. 0.015 | 207. 0.015 | 208. 0.015 |
| 209. 0.015 | 210. 0.016 | 211. 0.016 | 212. 0.017 |
| 213. 0.018 | 214. 0.018 | 215. 0.018 | 216. 0.018 |
| 217. 0.018 | 218. 0.018 | 219. 0.018 | 220. 0.018 |
| 221. 0.018 | 222. 0.019 | 223. 0.019 | 224. 0.019 |
| 225. 0.019 | 226. 0.019 | 227. 0.019 | 228. 0.019 |
| 229. 0.019 | 230. 0.019 | 231. 0.019 | 232. 0.019 |
| 233. 0.020 | 234. 0.020 | 235. 0.020 | 236. 0.020 |
| 237. 0.020 | 238. 0.020 | 239. 0.020 | 240. 0.020 |
| 241. 0.019 | 242. 0.019 | 243. 0.019 | 244. 0.019 |
| 245. 0.019 | 246. 0.018 | 247. 0.018 | 248. 0.018 |
| 249. 0.017 | 250. 0.017 | 251. 0.017 | 252. 0.017 |
| 253. 0.016 | 254. 0.016 | 255. 0.016 | 256. 0.016 |
| 257. 0.015 | 258. 0.015 | 259. 0.015 | 260. 0.014 |
| 261. 0.014 | 262. 0.014 | 263. 0.014 | 264. 0.014 |
| 265. 0.014 | 266. 0.014 | 267. 0.014 | 268. 0.015 |
| 269. 0.015 | 270. 0.015 | 271. 0.015 | 272. 0.016 |
| 273. 0.016 | 274. 0.016 | 275. 0.016 | 276. 0.016 |

|            |            |            |            |
|------------|------------|------------|------------|
| 277. 0.017 | 278. 0.017 | 279. 0.017 | 280. 0.018 |
| 281. 0.018 | 282. 0.018 | 283. 0.018 | 284. 0.018 |
| 285. 0.017 | 286. 0.017 | 287. 0.017 | 288. 0.016 |
| 289. 0.016 | 290. 0.016 | 291. 0.016 | 292. 0.016 |
| 293. 0.015 | 294. 0.014 | 295. 0.014 | 296. 0.014 |
| 297. 0.014 | 298. 0.014 | 299. 0.014 | 300. 0.014 |
| 301. 0.013 | 302. 0.013 | 303. 0.013 | 304. 0.013 |
| 305. 0.013 | 306. 0.013 | 307. 0.013 | 308. 0.013 |
| 309. 0.013 | 310. 0.013 | 311. 0.013 | 312. 0.013 |
| 313. 0.014 | 314. 0.014 | 315. 0.014 | 316. 0.014 |
| 317. 0.014 | 318. 0.014 | 319. 0.014 | 320. 0.014 |
| 321. 0.014 | 322. 0.014 | 323. 0.014 | 324. 0.014 |
| 325. 0.014 | 326. 0.014 | 327. 0.014 | 328. 0.014 |
| 329. 0.014 | 330. 0.014 | 331. 0.014 | 332. 0.015 |
| 333. 0.015 | 334. 0.016 | 335. 0.016 | 336. 0.016 |
| 337. 0.016 | 338. 0.016 | 339. 0.016 | 340. 0.016 |
| 341. 0.016 | 342. 0.016 | 343. 0.016 | 344. 0.016 |
| 345. 0.016 | 346. 0.017 | 347. 0.017 | 348. 0.017 |
| 349. 0.017 | 350. 0.017 | 351. 0.017 | 352. 0.017 |
| 353. 0.017 | 354. 0.017 | 355. 0.017 | 356. 0.017 |
| 357. 0.017 | 358. 0.017 | 359. 0.016 | 360. 0.016 |



Tang Ring Simulator Mated to the Clevis FWC Adapter Ring, 180024-006, VPT 0038.

The interference gap was measured using feeler gages at every degree location.

|     |       |     |       |     |       |     |       |
|-----|-------|-----|-------|-----|-------|-----|-------|
| 1.  | 0.020 | 2.  | 0.020 | 3.  | 0.019 | 4.  | 0.019 |
| 5.  | 0.019 | 6.  | 0.018 | 7.  | 0.018 | 8.  | 0.017 |
| 9.  | 0.017 | 10. | 0.017 | 11. | 0.016 | 12. | 0.016 |
| 13. | 0.016 | 14. | 0.015 | 15. | 0.015 | 16. | 0.015 |
| 17. | 0.015 | 18. | 0.015 | 19. | 0.016 | 20. | 0.015 |
| 21. | 0.014 | 22. | 0.014 | 23. | 0.014 | 24. | 0.014 |
| 25. | 0.014 | 26. | 0.014 | 27. | 0.014 | 28. | 0.014 |
| 29. | 0.014 | 30. | 0.014 | 31. | 0.014 | 32. | 0.015 |
| 33. | 0.015 | 34. | 0.016 | 35. | 0.016 | 36. | 0.016 |
| 37. | 0.016 | 38. | 0.016 | 39. | 0.016 | 40. | 0.017 |
| 41. | 0.017 | 42. | 0.017 | 43. | 0.017 | 44. | 0.017 |
| 45. | 0.017 | 46. | 0.016 | 47. | 0.016 | 48. | 0.016 |
| 49. | 0.016 | 50. | 0.016 | 51. | 0.017 | 52. | 0.017 |
| 53. | 0.017 | 54. | 0.017 | 55. | 0.017 | 56. | 0.017 |
| 57. | 0.018 | 58. | 0.017 | 59. | 0.017 | 60. | 0.017 |
| 61. | 0.018 | 62. | 0.017 | 63. | 0.017 | 64. | 0.017 |
| 65. | 0.017 | 66. | 0.016 | 67. | 0.016 | 68. | 0.016 |
| 69. | 0.016 | 70. | 0.016 | 71. | 0.015 | 72. | 0.015 |
| 73. | 0.015 | 74. | 0.015 | 75. | 0.015 | 76. | 0.015 |
| 77. | 0.014 | 78. | 0.014 | 79. | 0.014 | 80. | 0.014 |
| 81. | 0.014 | 82. | 0.014 | 83. | 0.013 | 84. | 0.013 |
| 85. | 0.013 | 86. | 0.013 | 87. | 0.012 | 88. | 0.012 |

|      |       |      |       |      |       |      |       |
|------|-------|------|-------|------|-------|------|-------|
| 89.  | 0.012 | 90.  | 0.012 | 91.  | 0.012 | 92.  | 0.012 |
| 93.  | 0.011 | 94.  | 0.011 | 95.  | 0.011 | 96.  | 0.011 |
| 97.  | 0.011 | 98.  | 0.011 | 99.  | 0.011 | 100. | 0.011 |
| 101. | 0.010 | 102. | 0.010 | 103. | 0.010 | 104. | 0.010 |
| 105. | 0.010 | 106. | 0.011 | 107. | 0.011 | 108. | 0.011 |
| 109. | 0.011 | 110. | 0.011 | 111. | 0.011 | 112. | 0.011 |
| 113. | 0.011 | 114. | 0.011 | 115. | 0.011 | 116. | 0.011 |
| 117. | 0.012 | 118. | 0.012 | 119. | 0.012 | 120. | 0.013 |
| 121. | 0.013 | 122. | 0.014 | 123. | 0.014 | 124. | 0.014 |
| 125. | 0.014 | 126. | 0.014 | 127. | 0.015 | 128. | 0.015 |
| 129. | 0.015 | 130. | 0.015 | 131. | 0.016 | 132. | 0.016 |
| 133. | 0.016 | 134. | 0.016 | 135. | 0.016 | 136. | 0.016 |
| 137. | 0.016 | 138. | 0.016 | 139. | 0.017 | 140. | 0.017 |
| 141. | 0.016 | 142. | 0.016 | 143. | 0.016 | 144. | 0.016 |
| 145. | 0.016 | 146. | 0.016 | 147. | 0.015 | 148. | 0.015 |
| 149. | 0.015 | 150. | 0.015 | 151. | 0.015 | 152. | 0.015 |
| 153. | 0.015 | 154. | 0.015 | 155. | 0.015 | 156. | 0.015 |
| 157. | 0.015 | 158. | 0.015 | 159. | 0.015 | 160. | 0.015 |
| 161. | 0.015 | 162. | 0.015 | 163. | 0.015 | 164. | 0.016 |
| 165. | 0.016 | 166. | 0.016 | 167. | 0.016 | 168. | 0.016 |
| 169. | 0.016 | 170. | 0.017 | 171. | 0.017 | 172. | 0.017 |
| 173. | 0.017 | 174. | 0.017 | 175. | 0.017 | 176. | 0.017 |
| 177. | 0.018 | 178. | 0.018 | 179. | 0.018 | 180. | 0.018 |
| 181. | 0.018 | 182. | 0.018 | 183. | 0.018 | 184. | 0.018 |
| 185. | 0.018 | 186. | 0.019 | 187. | 0.019 | 188. | 0.019 |

|            |            |            |            |
|------------|------------|------------|------------|
| 189. 0.019 | 190. 0.019 | 191. 0.019 | 192. 0.020 |
| 193. 0.020 | 194. 0.020 | 195. 0.021 | 196. 0.021 |
| 197. 0.021 | 198. 0.021 | 199. 0.021 | 200. 0.021 |
| 201. 0.021 | 202. 0.021 | 203. 0.021 | 204. 0.021 |
| 205. 0.021 | 206. 0.022 | 207. 0.023 | 208. 0.023 |
| 209. 0.023 | 210. 0.023 | 211. 0.023 | 212. 0.024 |
| 213. 0.024 | 214. 0.024 | 215. 0.024 | 216. 0.025 |
| 217. 0.025 | 218. 0.025 | 219. 0.025 | 220. 0.026 |
| 221. 0.027 | 222. 0.027 | 223. 0.028 | 224. 0.028 |
| 225. 0.029 | 226. 0.029 | 227. 0.030 | 228. 0.030 |
| 229. 0.030 | 230. 0.031 | 231. 0.031 | 232. 0.032 |
| 233. 0.032 | 234. 0.032 | 235. 0.033 | 236. 0.033 |
| 237. 0.033 | 238. 0.033 | 239. 0.034 | 240. 0.034 |
| 241. 0.034 | 242. 0.034 | 243. 0.034 | 244. 0.034 |
| 245. 0.034 | 246. 0.033 | 247. 0.033 | 248. 0.033 |
| 249. 0.032 | 250. 0.032 | 251. 0.032 | 252. 0.031 |
| 253. 0.031 | 254. 0.031 | 255. 0.030 | 256. 0.030 |
| 257. 0.030 | 258. 0.030 | 259. 0.029 | 260. 0.029 |
| 261. 0.028 | 262. 0.028 | 263. 0.027 | 264. 0.027 |
| 265. 0.026 | 266. 0.026 | 267. 0.026 | 268. 0.025 |
| 269. 0.025 | 270. 0.025 | 271. 0.024 | 272. 0.024 |
| 273. 0.024 | 274. 0.024 | 275. 0.024 | 276. 0.023 |
| 277. 0.023 | 278. 0.022 | 279. 0.022 | 280. 0.022 |
| 281. 0.022 | 282. 0.021 | 283. 0.021 | 284. 0.021 |
| 285. 0.020 | 286. 0.020 | 287. 0.020 | 288. 0.019 |

|            |            |            |            |
|------------|------------|------------|------------|
| 289. 0.018 | 290. 0.018 | 291. 0.018 | 292. 0.017 |
| 293. 0.017 | 294. 0.017 | 295. 0.017 | 296. 0.017 |
| 297. 0.016 | 298. 0.016 | 299. 0.016 | 300. 0.016 |
| 301. 0.016 | 302. 0.016 | 303. 0.016 | 304. 0.016 |
| 305. 0.016 | 306. 0.016 | 307. 0.016 | 308. 0.016 |
| 309. 0.016 | 310. 0.016 | 311. 0.016 | 312. 0.016 |
| 313. 0.016 | 314. 0.016 | 315. 0.017 | 316. 0.017 |
| 317. 0.017 | 318. 0.017 | 319. 0.017 | 320. 0.018 |
| 321. 0.018 | 322. 0.018 | 323. 0.018 | 324. 0.018 |
| 325. 0.018 | 326. 0.018 | 327. 0.018 | 328. 0.018 |
| 329. 0.018 | 330. 0.019 | 331. 0.019 | 332. 0.019 |
| 333. 0.019 | 334. 0.019 | 335. 0.019 | 336. 0.019 |
| 337. 0.019 | 338. 0.020 | 339. 0.020 | 340. 0.020 |
| 341. 0.020 | 342. 0.020 | 343. 0.021 | 344. 0.021 |
| 345. 0.021 | 346. 0.021 | 347. 0.021 | 348. 0.021 |
| 349. 0.021 | 350. 0.021 | 351. 0.021 | 352. 0.021 |
| 353. 0.021 | 354. 0.021 | 355. 0.021 | 356. 0.021 |
| 357. 0.021 | 358. 0.021 | 359. 0.021 | 360. 0.021 |

Tang Ring Simulator Mated to the Clevis FWC Adapter Ring, 180024-006, VPT 0042.

The interference gap was measured using feeler gages at every degree location.

|          |           |           |           |
|----------|-----------|-----------|-----------|
| 1. 0.014 | 2. 0.014  | 3. 0.014  | 4. 0.013  |
| 5. 0.013 | 6. 0.013  | 7. 0.012  | 8. 0.012  |
| 9. 0.011 | 10. 0.011 | 11. 0.010 | 12. 0.010 |

|            |            |            |            |
|------------|------------|------------|------------|
| 13. 0.010  | 14. 0.009  | 15. 0.009  | 16. 0.008  |
| 17. 0.008  | 18. 0.009  | 19. 0.009  | 20. 0.008  |
| 21. 0.007  | 22. 0.007  | 23. 0.007  | 24. 0.007  |
| 25. 0.007  | 26. 0.008  | 27. 0.009  | 28. 0.009  |
| 29. 0.009  | 30. 0.009  | 31. 0.010  | 32. 0.010  |
| 33. 0.010  | 34. 0.011  | 35. 0.011  | 36. 0.012  |
| 37. 0.012  | 38. 0.013  | 39. 0.013  | 40. 0.014  |
| 41. 0.014  | 42. 0.014  | 43. 0.014  | 44. 0.014  |
| 45. 0.015  | 46. 0.015  | 47. 0.015  | 48. 0.015  |
| 49. 0.016  | 50. 0.016  | 51. 0.017  | 52. 0.018  |
| 53. 0.018  | 54. 0.018  | 55. 0.018  | 56. 0.018  |
| 57. 0.019  | 58. 0.020  | 59. 0.020  | 60. 0.021  |
| 61. 0.021  | 62. 0.021  | 63. 0.021  | 64. 0.021  |
| 65. 0.022  | 66. 0.022  | 67. 0.023  | 68. 0.023  |
| 69. 0.024  | 70. 0.024  | 71. 0.024  | 72. 0.024  |
| 73. 0.024  | 74. 0.024  | 75. 0.024  | 76. 0.024  |
| 77. 0.024  | 78. 0.024  | 79. 0.024  | 80. 0.024  |
| 81. 0.024  | 82. 0.024  | 83. 0.024  | 84. 0.023  |
| 85. 0.023  | 86. 0.022  | 87. 0.022  | 88. 0.022  |
| 89. 0.021  | 90. 0.021  | 91. 0.020  | 92. 0.020  |
| 93. 0.019  | 94. 0.018  | 95. 0.018  | 96. 0.017  |
| 97. 0.017  | 98. 0.016  | 99. 0.016  | 100. 0.015 |
| 101. 0.014 | 102. 0.014 | 103. 0.014 | 104. 0.014 |
| 105. 0.013 | 106. 0.013 | 107. 0.012 | 108. 0.012 |
| 109. 0.011 | 110. 0.011 | 111. 0.010 | 112. 0.010 |

|            |            |            |            |
|------------|------------|------------|------------|
| 113. 0.010 | 114. 0.010 | 115. 0.010 | 116. 0.009 |
| 117. 0.009 | 118. 0.009 | 119. 0.009 | 120. 0.009 |
| 121. 0.009 | 122. 0.010 | 123. 0.010 | 124. 0.010 |
| 125. 0.010 | 126. 0.011 | 127. 0.011 | 128. 0.011 |
| 129. 0.011 | 130. 0.011 | 131. 0.012 | 132. 0.012 |
| 133. 0.013 | 134. 0.013 | 135. 0.014 | 136. 0.014 |
| 137. 0.014 | 138. 0.014 | 139. 0.014 | 140. 0.014 |
| 141. 0.015 | 142. 0.015 | 143. 0.016 | 144. 0.016 |
| 145. 0.016 | 146. 0.016 | 147. 0.016 | 148. 0.017 |
| 149. 0.017 | 150. 0.017 | 151. 0.017 | 152. 0.017 |
| 153. 0.017 | 154. 0.017 | 155. 0.017 | 156. 0.017 |
| 157. 0.017 | 158. 0.017 | 159. 0.017 | 160. 0.017 |
| 161. 0.017 | 162. 0.017 | 163. 0.016 | 164. 0.016 |
| 165. 0.016 | 166. 0.016 | 167. 0.016 | 168. 0.016 |
| 169. 0.016 | 170. 0.016 | 171. 0.016 | 172. 0.016 |
| 173. 0.016 | 174. 0.016 | 175. 0.016 | 176. 0.016 |
| 177. 0.016 | 178. 0.016 | 179. 0.016 | 180. 0.016 |
| 181. 0.016 | 182. 0.016 | 183. 0.016 | 184. 0.017 |
| 185. 0.017 | 186. 0.017 | 187. 0.017 | 188. 0.017 |
| 189. 0.017 | 190. 0.017 | 191. 0.017 | 192. 0.017 |
| 193. 0.017 | 194. 0.017 | 195. 0.017 | 196. 0.017 |
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| 209. 0.017 | 210. 0.017 | 211. 0.017 | 212. 0.017 |

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| 213. 0.017 | 214. 0.017 | 215. 0.018 | 216. 0.018 |
| 217. 0.018 | 218. 0.018 | 219. 0.018 | 220. 0.018 |
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| 225. 0.018 | 226. 0.019 | 227. 0.019 | 228. 0.020 |
| 229. 0.020 | 230. 0.021 | 231. 0.021 | 232. 0.021 |
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| 253. 0.023 | 254. 0.023 | 255. 0.023 | 256. 0.023 |
| 257. 0.023 | 258. 0.024 | 259. 0.024 | 260. 0.024 |
| 261. 0.024 | 262. 0.024 | 263. 0.024 | 264. 0.024 |
| 265. 0.025 | 266. 0.025 | 267. 0.025 | 268. 0.025 |
| 269. 0.025 | 270. 0.025 | 271. 0.025 | 272. 0.026 |
| 273. 0.026 | 274. 0.026 | 275. 0.026 | 276. 0.027 |
| 277. 0.027 | 278. 0.027 | 279. 0.027 | 280. 0.027 |
| 281. 0.027 | 282. 0.027 | 283. 0.027 | 284. 0.028 |
| 285. 0.028 | 286. 0.028 | 287. 0.028 | 288. 0.028 |
| 289. 0.027 | 290. 0.027 | 291. 0.026 | 292. 0.026 |
| 293. 0.026 | 294. 0.026 | 295. 0.026 | 296. 0.026 |
| 297. 0.026 | 298. 0.026 | 299. 0.026 | 300. 0.026 |
| 301. 0.026 | 302. 0.026 | 303. 0.026 | 304. 0.026 |
| 305. 0.026 | 306. 0.026 | 307. 0.026 | 308. 0.026 |
| 309. 0.026 | 310. 0.026 | 311. 0.026 | 312. 0.026 |

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| 313. 0.026 | 314. 0.026 | 315. 0.026 | 316. 0.026 |
| 317. 0.026 | 318. 0.026 | 319. 0.026 | 320. 0.026 |
| 321. 0.026 | 322. 0.026 | 323. 0.026 | 324. 0.026 |
| 325. 0.025 | 326. 0.025 | 327. 0.025 | 328. 0.025 |
| 329. 0.024 | 330. 0.024 | 331. 0.024 | 332. 0.024 |
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| 341. 0.022 | 342. 0.021 | 343. 0.021 | 344. 0.021 |
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| 349. 0.021 | 350. 0.020 | 351. 0.020 | 352. 0.020 |
| 353. 0.019 | 354. 0.019 | 355. 0.018 | 356. 0.018 |
| 357. 0.017 | 358. 0.017 | 359. 0.016 | 360. 0.016 |

Appendix E  
3- $\sigma$  Uncertainty for PMD Radial Measurements

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# Thiokol CORPORATION

26 October 1989  
2830-FY90-M095

TO: Dave Porter

CC: Mark R. James, Ken W. Wilkes, Wayne L. Berndt,  
S. John Bennett

FROM: A. S. Allen  
Analytical Capability Development

SUBJECT: Estimates for Uncertainties in SRM Segment Interferences  
Based on PMD-002 Measurements

The purpose of this report is to document the amount of uncertainty inherent in predicting interferences for possible SRM segment mates given tang and clevis measurements using PMD-002. For this report, interference is defined as tang-clevis. That is, a positive number indicates interference while a negative number indicates a gap. All measurements of uncertainty are shown in radial mils.

Given tang and clevis measurements using PMD-002, our best prediction for interference is:

$$\text{Predicted Interference} = \text{Tip 11} - \text{Tip 9} + \text{Predicted Bias}$$

Therefore our best estimate for uncertainty in the predicted interference is the root sum squares of the uncertainties for each term in the equation as follows:

$$\sigma_{\text{pred int.}} = [ \sigma_{\text{Tip 11}}^2 + \sigma_{\text{Tip 9}}^2 + \sigma_{\text{Pred Bias}}^2 ]^{1/2}$$

The methodology used to generate estimates for the three components of uncertainty shown above will now be presented.

## Uncertainty in Tip 11 Measures

The inherent variation in the tang measurement using a PMD-002 Tip 11 was estimated using the following strategy. One tang (PN 1U52982-03, SN 0000027) was measured using 2 passes of the PMD-002 Tip 11. Then the PMD was removed and replaced and 2 more passes were made. This was repeated a third time for a total of 6 measurements. Then the PMD was recalibrated and the whole process repeated. Then, after 5 calibrations

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E-2

30 measures of the tang using Tip 11 had been obtained. Then the data was analyzed in using Analysis of Variance in order to estimate the individual components of variance due to calibrating, removing and repeat measuring using Tip 11. Results are as follows:

| <u>Component</u>              | <u>1-Sigma Uncertainty<br/>(Radial Mils)</u> |
|-------------------------------|--|
| Calibration ( $\sigma_c$ )    | .3509  |
| Remove/Replace ( $\sigma_R$ ) | .1267  |
| Repeat Pass ( $\sigma_p$ )    | .0315  |

Then, the total uncertainty for a production mode measurement of a tang using 2 passes with a Tip 11 (1 calibration, 1 replace) -

$$[(.3509)^2 + (.1267)^2 + (.0315)^2/2]^{1/2} = .3737 \text{ (1-sigma)}$$

$$\text{or} = 1.1211 \text{ (3-sigma)}$$

#### Uncertainty in Tip 9 Measures

The same measurement strategy previously described for Tip 11 was also used to estimate the uncertainty for Tip 9. Results are as follows:

| <u>Component</u>              | <u>1-Sigma Uncertainty<br/>(Radial Mils)</u> |
|-------------------------------|--|
| Calibration ( $\sigma_c$ )    | .3027  |
| Remove/Replace ( $\sigma_R$ ) | .2076  |
| Repeat Pass ( $\sigma_p$ )    | .0605  |

Again, the total uncertainty for a production mode measurement of a clevis using 2 passes with a Tip 9 -

$$[(.3027)^2 + (.2076)^2 + (.0605)^2/2]^{1/2} = .3695 \text{ (1-sigma)}$$

$$\text{or} = 1.1086 \text{ (3-sigma)}$$

#### Uncertainty in Predicted Bias

The predicted bias in the average in the difference between predicted interference (based on Tip 9 and Tip 11) measures) and actual measured interference using a feeler gage. The tangs and clevis selected for these tests are deliberately chosen to produce a gap (negative interference) so actual feeler gage measures are possible. Six measurements of a single tang (3 calibrations, 2 passes each) were compared against 6 measurements (3 calibrations, 2 passes) each on three separate clevis parts (UPT0046,38,42). Predicted interferences were calculated as follows:

| <u>Tang</u> (Tip 11) | - | <u>Clevis</u> (Tip9) | - | <u>Predicted Interference</u> (Radial Mils) |
|----------------------|---|----------------------|---|---|
| 71.84715             | - | 71.8614              | - | .01425                                      |
| 71.84715             | - | 71.8687              | - | .02155                                      |
| 71.84715             | - | 71.8679              | - | .02075                                      |

Then the predicted interferences shown above were compared with the actual interferences (negative) measured with the feeler gage.

| <u>Feeler Gage</u><br><u>Ave. Interference</u> | - | <u>Predicted</u><br><u>Interference</u> | - | <u>Bias (Radial Mils)</u> |
|--|---|---|---|---------------------------|
| - .0115  | - | - .01425                                | - | .00275                    |
| - .0193  | - | - .02155                                | - | .00225                    |
| - .0192  | - | - .02075                                | - | .00155                    |
|  |   |   |   | <hr/>                     |
|  |   |   |   | .00218 - Ave Bias         |

Since Predicted Bias -

$$[ (\text{Feeler Gage} - (\text{Tip 11} - \text{Tip 9})) ]$$

then the uncertainty in Predicted Bias (for 1 segment mate)

$$= [ \sigma_{\text{Gage}}^2 + \sigma_{\text{Tip 11}}^2 + \sigma_{\text{Tip 9}}^2 ]$$

In this estimate of predicted bias, however, our Tip 11 and Tip 9 uncertainties were not as large as the production mode uncertainties calculated earlier because 6 measures (3 calibrations) of each tang and clevis were made prior to mating. Now, the uncertainties in Tip 11 and Tip 9 for this bias estimate only are calculated as:

$$\begin{aligned} \text{Tip 11} &= [ (.3509)^2/3 + (.1267)^2 + (.0315)^2/2 ]^{1/2} = .2400 \text{ (1-sigma)} \\ &\text{or} = .7200 \text{ (3-sigma)} \end{aligned}$$

$$\begin{aligned} \text{Tip 9} &= [ (.3027)^2/3 + (.2076)^2 + (.0605)^2/2 ]^{1/2} = .2747 \text{ (1-sigma)} \\ &\text{or} = .8242 \text{ (3-sigma)} \end{aligned}$$

The tolerance accuracy for the feeler gage is determined to be .0075 (radial mils) or .0025 1-sigma.

Then the overall uncertainty for predicted bias (1 mate)

$$= [ (.0025)^2 + (.2400)^2 + (.2747)^2 ]^{1/2} = .3648 \text{ (1-sigma)} \\ \text{or} = 1.0943 \text{ (3-sigma)}$$

Since 3 matings were used to estimate the bias, the uncertainty for predicted bias can be calculated as follows:

$$(.3648) / \sqrt{3} = .2106 \text{ (1-sigma)} \\ \text{or} = .6319 \text{ (3-sigma)}$$

Uncertainty for Predicted Interference (PMD-002)

Now the total uncertainty in predicted interference when tang and clevis have been measured with 2 passes each (regular production mode) using PMD-002 is:

$$\sigma_{\text{pred int}} = [ (.3737)^2 + (.3695)^2 + (.2106)^2 ]^{1/2} = .5662 \text{ (1-sigma)} \\ \text{or} = 1.6985 \text{ (3-sigma)} \\ \text{radial mils}$$

*Andrew S. Allen*

A. Allen

AA/jk

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